Small-x and Forward Measurements at STAR

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For the STAR Collaboration

DIS 2011

Newport News, VA

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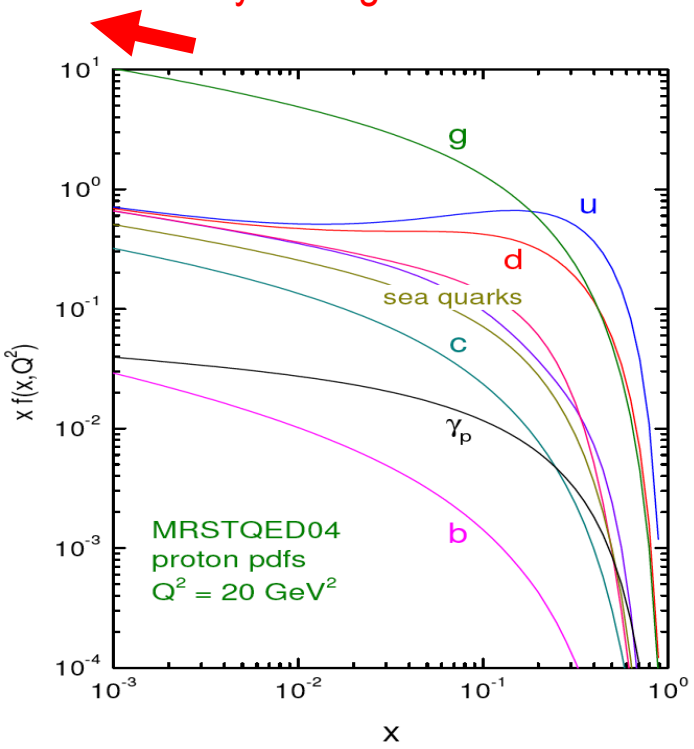
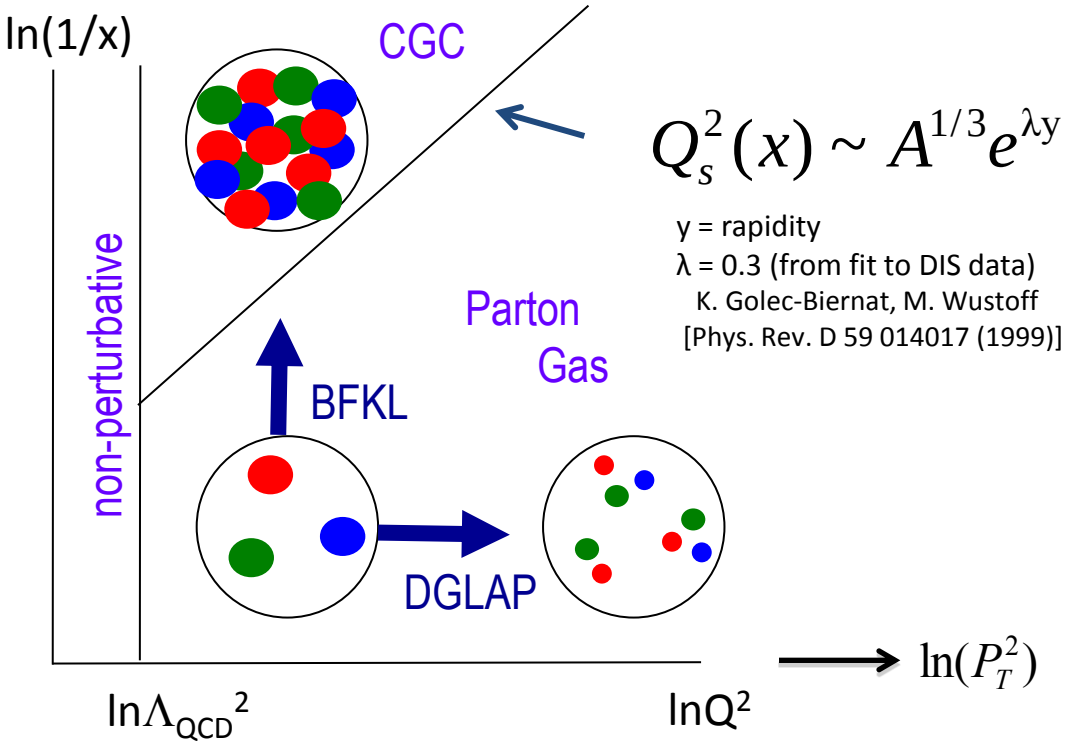
Low-x and Color Glass Condensate

Gluon density can't grow forever.





$$Q_s^2(x) \sim A^{1/3} e^{\lambda y}$$

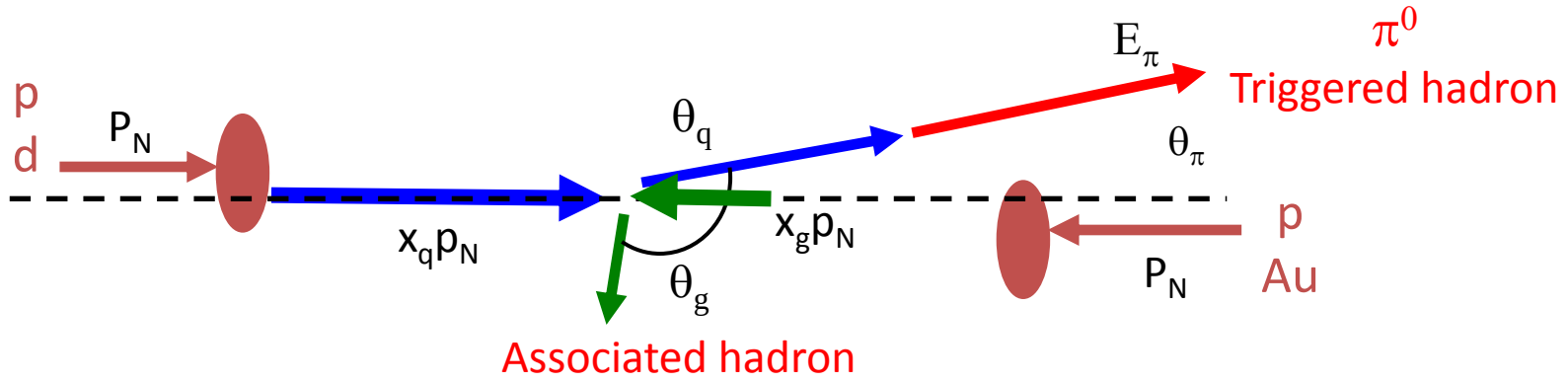
y = rapidity
λ = 0.3 (from fit to DIS data)
K. Golec-Biernat, M. Wustoff
[Phys. Rev. D 59 014017 (1999)]

$$x \sim \frac{2p_T}{\sqrt{s}} e^{-y}$$

Gluon densities rise at low-x and recombination becomes important.
Non-linear contributions to evolution need to be included.
Color Glass Condensate: semi-classical effective field theory for computing low-x gluons in nuclei.

Saturation can apply for: Low-x, Large sqrt(s), Large y, Large A

Kinematics



- Hadronic probe (p,d) directly couples with gluons in target (p, Au)
- Forward scattering probes asymmetric partonic collisions

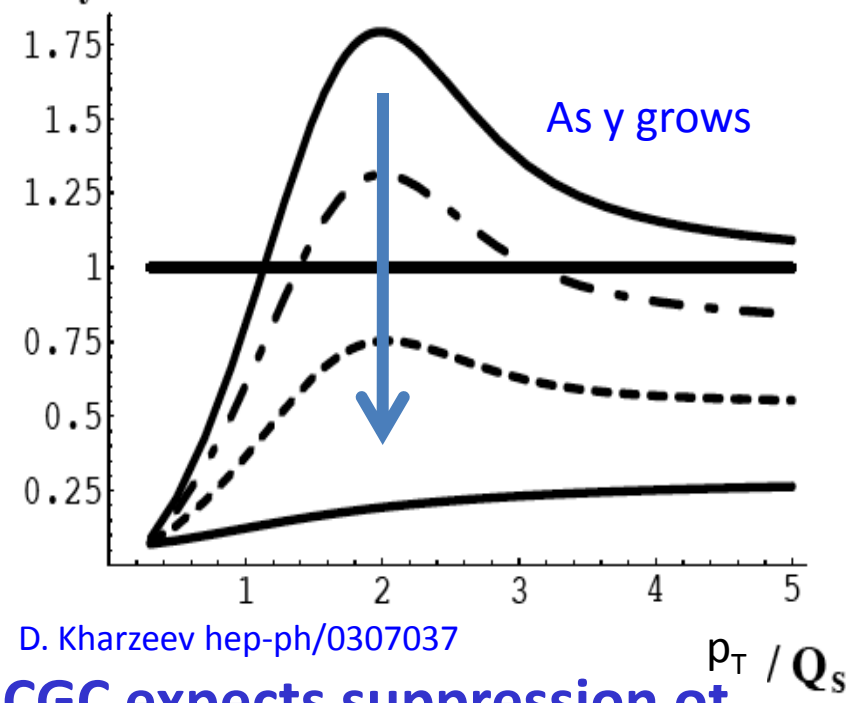
high-x valence quarks on **low-x gluons** ($0.001 < x_g < 0.1$)

$x_F = x_1 - x_2$ $\quad$ x_2 = small $\rightarrow$ $x_F \approx x_1$ = large

- Forward Rapidity + Nuclear Target = best opportunity to probe gluon saturation

Expectations From Color Glass Condensate

$$R_{dAu} = \frac{1}{2*197}\frac{\sigma_{dAu}}{\sigma_{pp}}$$



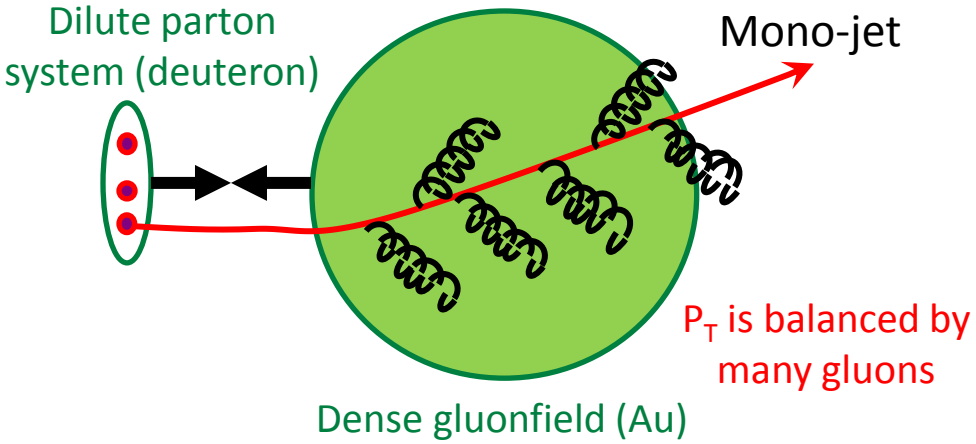
D. Kharzeev hep-ph/0307037

CGC expects suppression of forward hadron production in p(d)A collisions compared to p+p

pQCD 2➔2 process =back-to-back di-jet

With high gluon density this goes to:

2➔1 (or 2➔many) process = Mono-jet ?

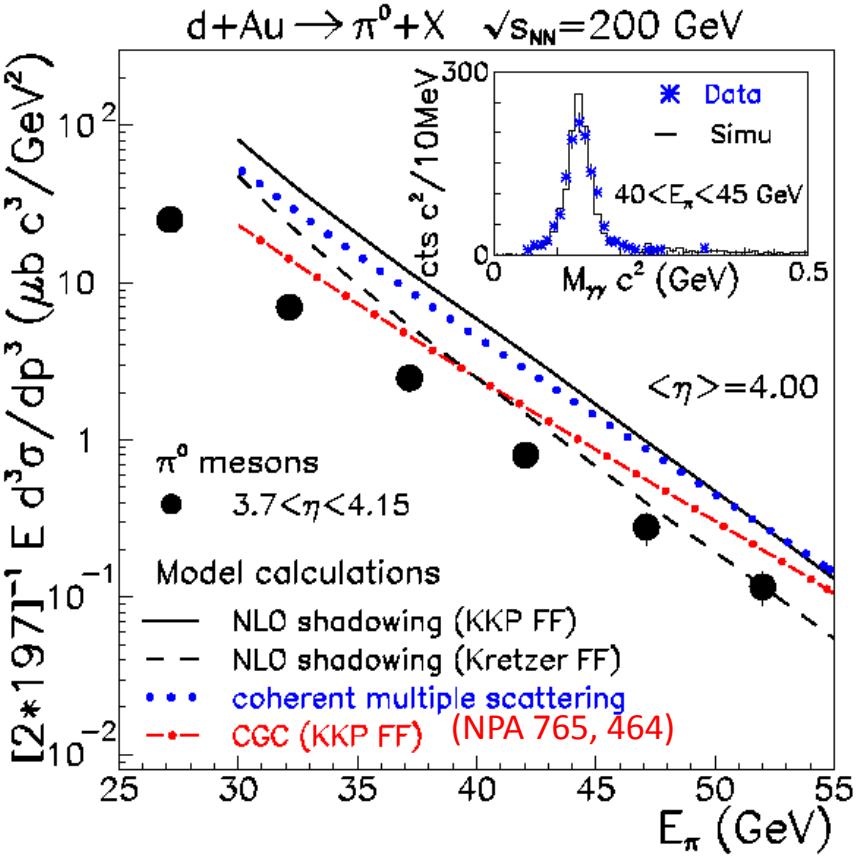


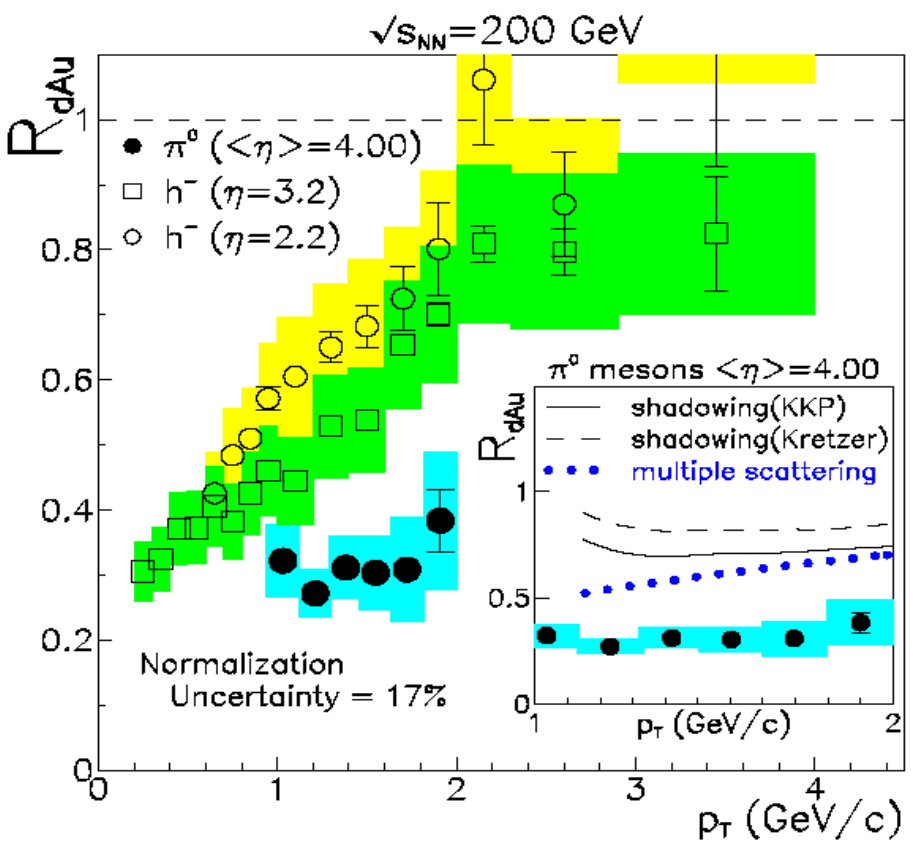
CGC predicts suppression of back-to-back correlations

STAR Forward π^0

$\eta = 4.0$

PRL 97, 152302 (2006)





Sizable suppression

pQCD+Shadowing expects suppression, but not enough

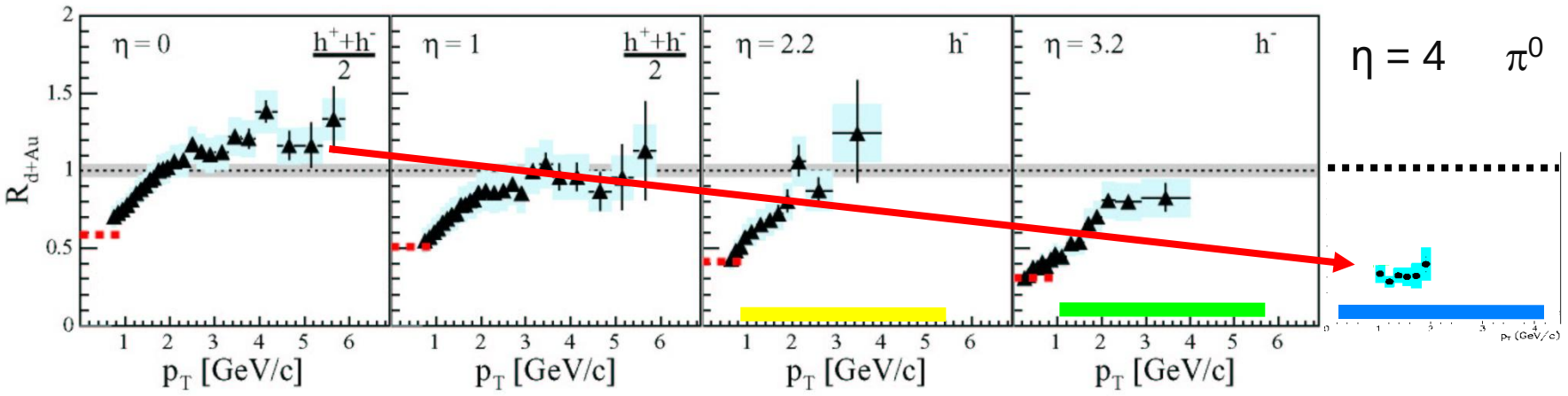
CGC gives best description of p_T dependence

R_{dAu} Rapidity Dependence

$\eta = 0 \rightarrow 4$

BRAHMS PRL 93, 242303

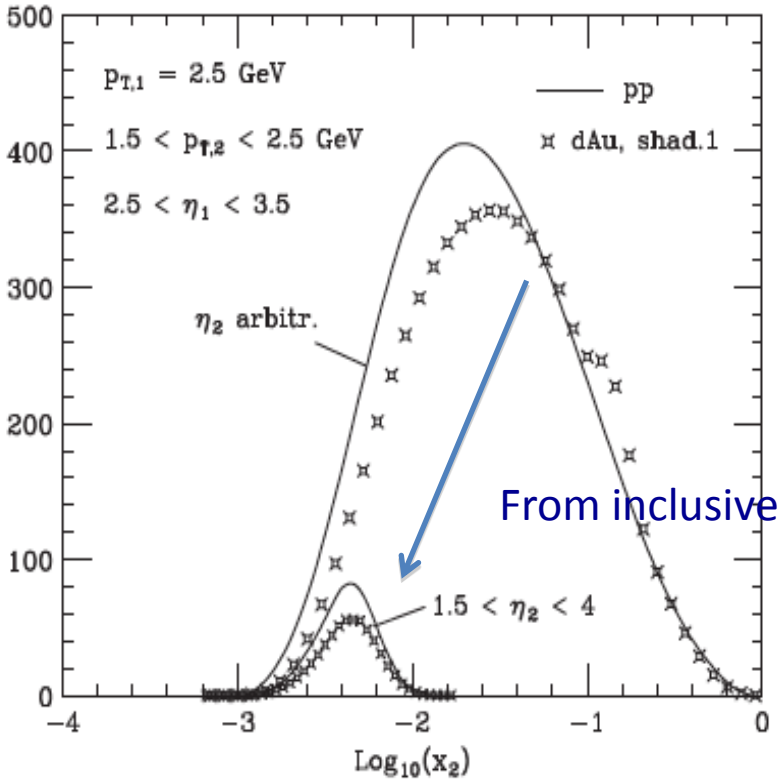
STAR PRL 97, 152302



Observe significant rapidity dependence
similar to expectations from the CGC framework

Di-Hadron Correlations

Phys. Lett. B603 (2004) 173



- Inclusive production measures integral of broad x range
- Measuring correlations between two forward π^0 probes a limited, smaller x range

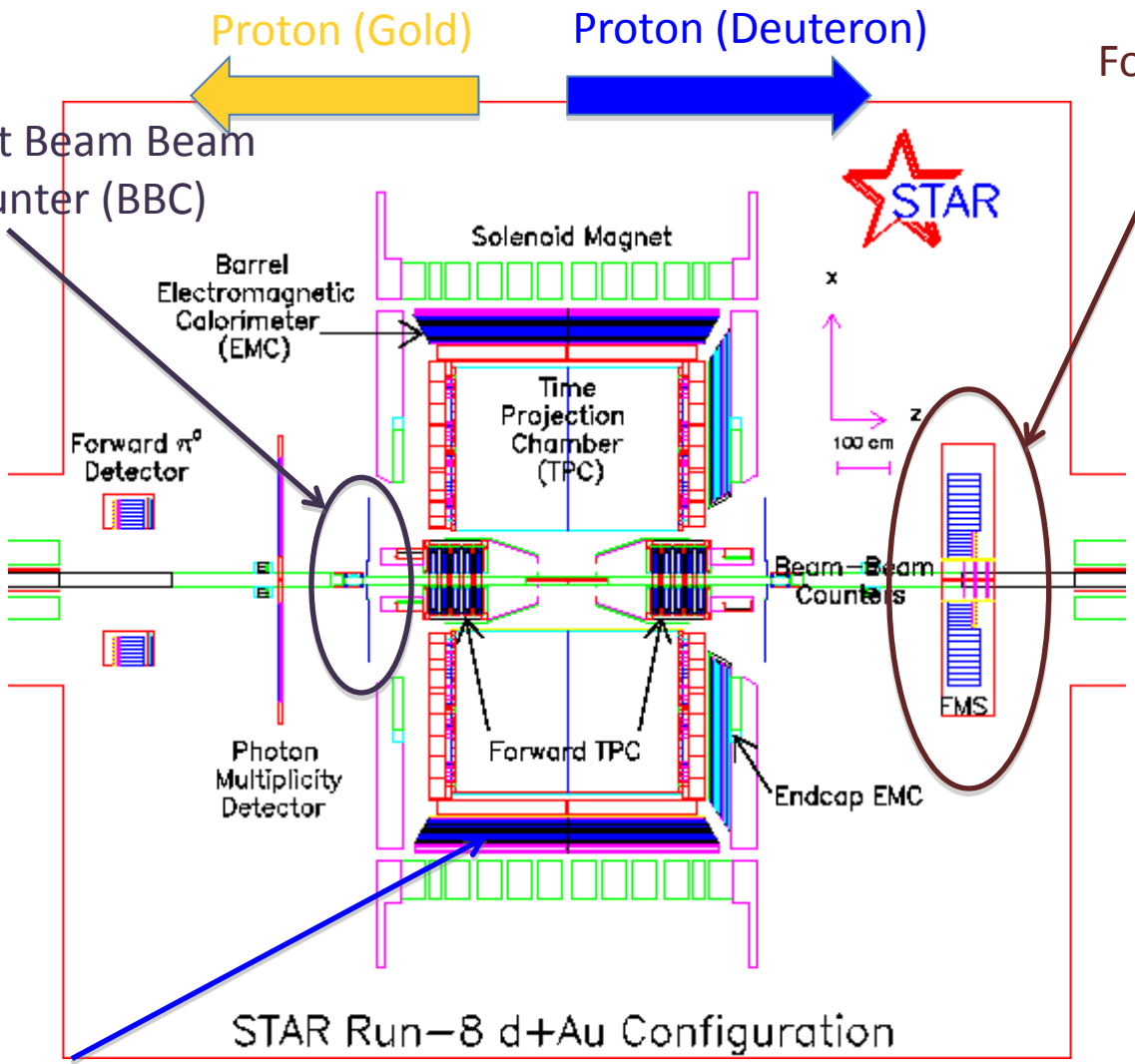
From inclusive π^0 to π^0-π^0

$$x_+ \approx \frac{p_T}{\sqrt{s}}\left(e^{+\eta_1} + e^{+\eta_2}\right) \xrightarrow[\eta_1 >> \eta_2]{} x_F$$

$$x_- \approx \frac{p_T}{\sqrt{s}}\left(e^{-\eta_1} + e^{-\eta_2}\right) \xrightarrow[\eta_1 >> \eta_2]{} x_F e^{-(\eta_1+\eta_2)}$$

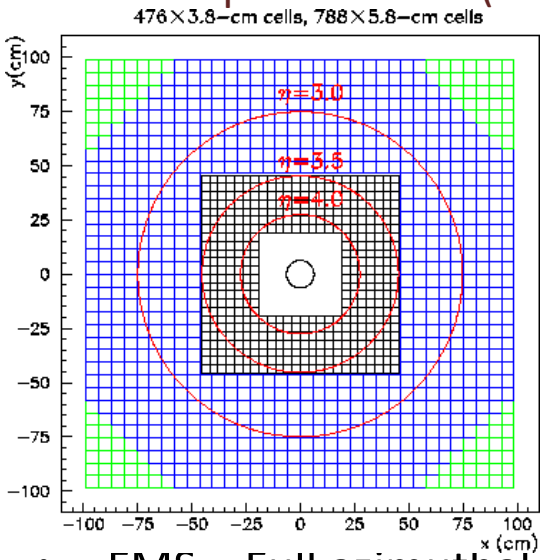
Correlations between two forward π^0 are more sensitive to low-x gluons than inclusive production

STAR Run 8 Configuration

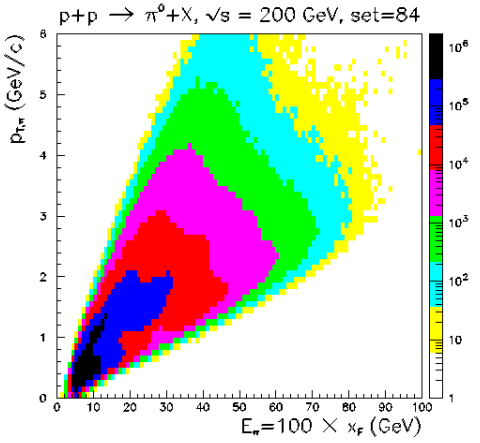


Barrel electro-magnetic calorimeter (BEMC)

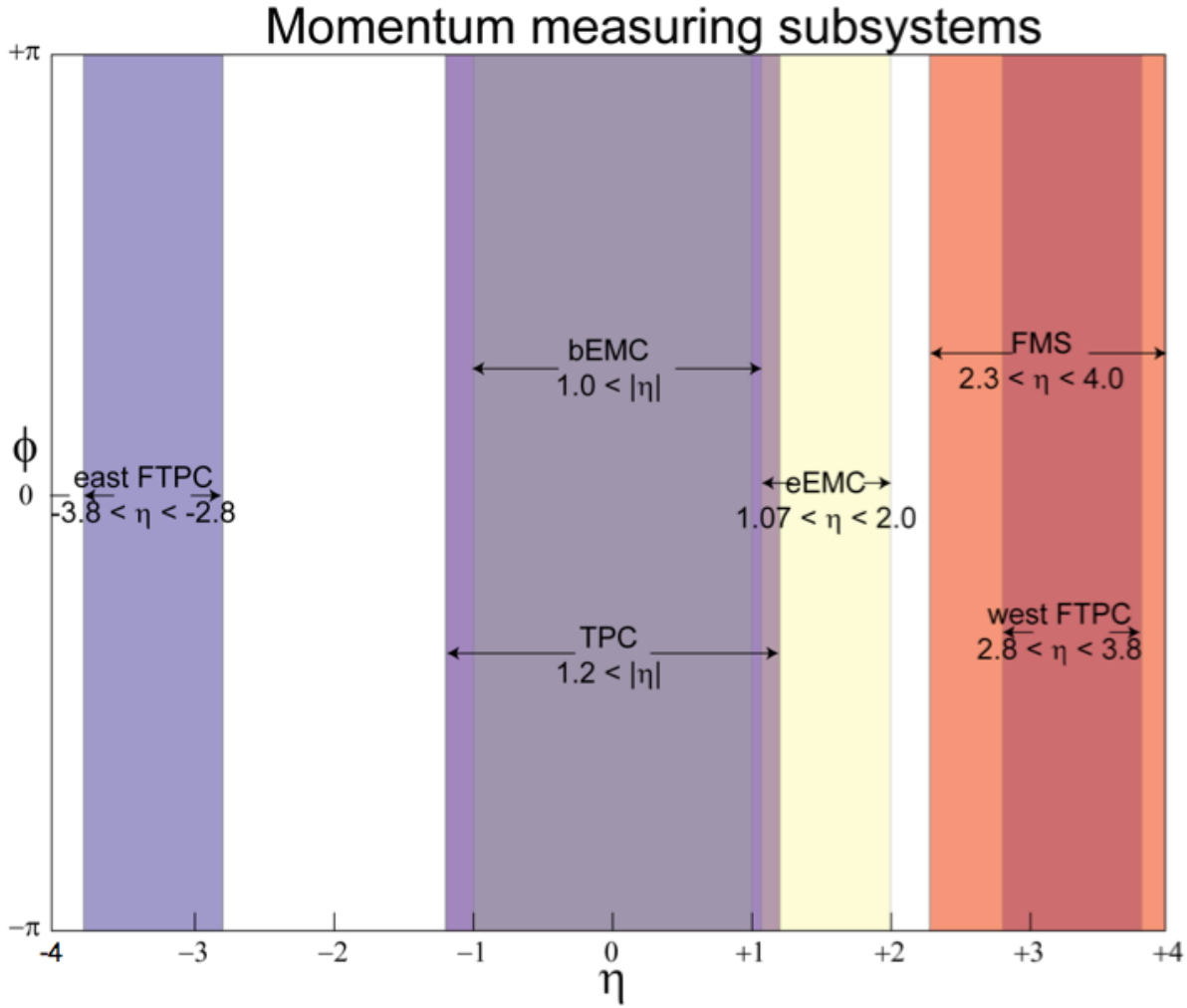
Forward Meson Spectrometer (FMS)



- FMS = Full azimuthal coverage for $2.5 < \eta < 4$



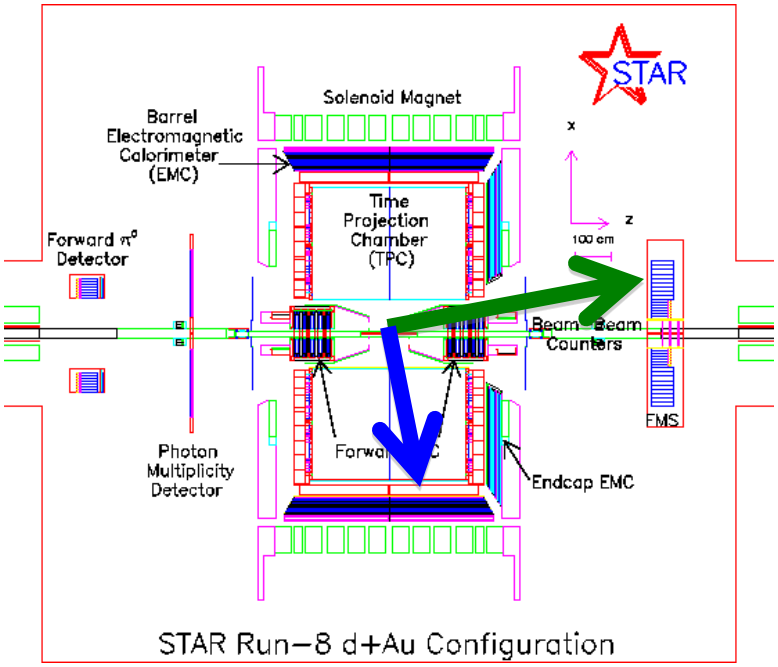
STAR η-ϕ Coverage



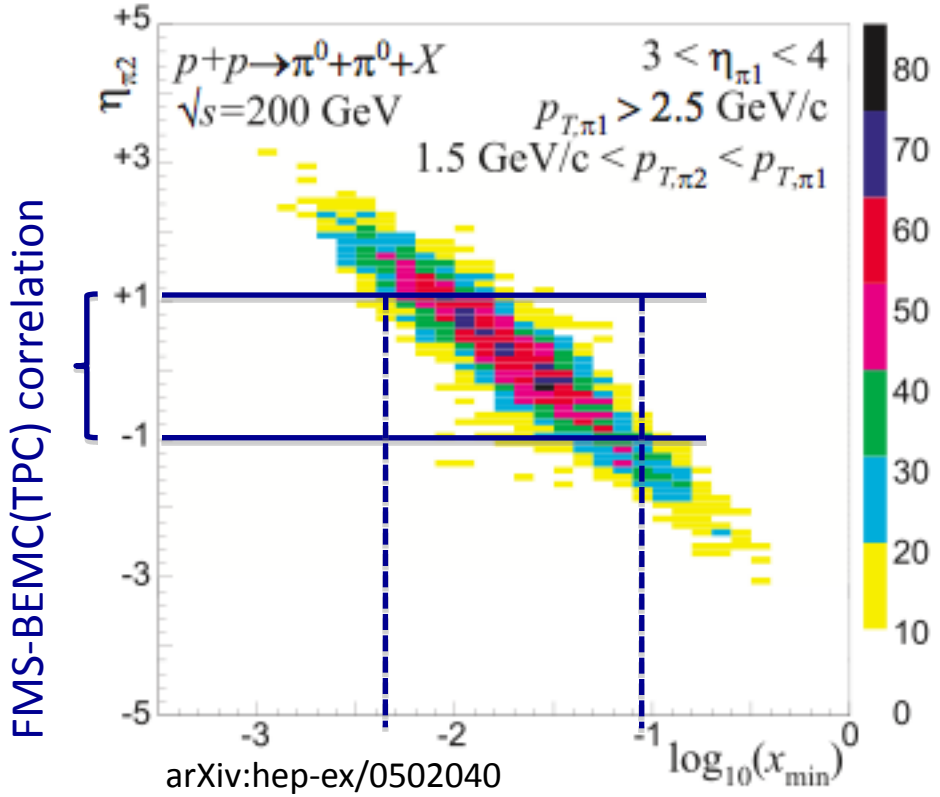
STAR has nearly hermetic coverage over full azimuthal range and wide pseudorapidity range

Forward-Mid Rapidity Correlations

- Probe nuclei gluon density at 0.008 < x < 0.07



PYTHIA simulation



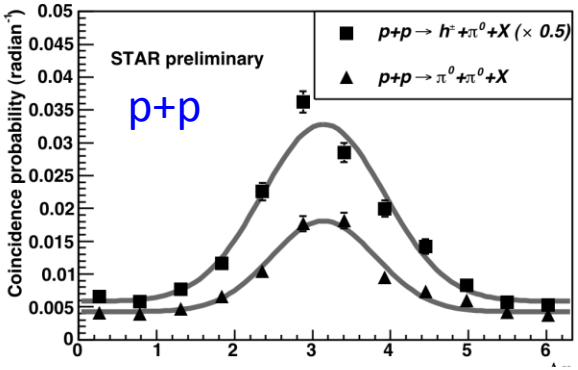
arXiv:hep-ex/0502040

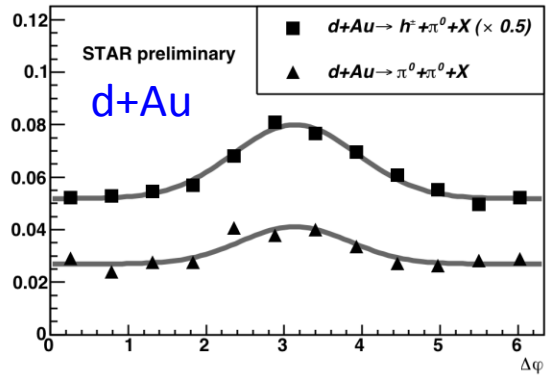
When triggering on a forward rapidity π^0, the rapidity of the associated π^0 is correlated with the x_{bj} of the soft parton involved in the partonic scattering.

Forward-Mid Rapidity Correlations

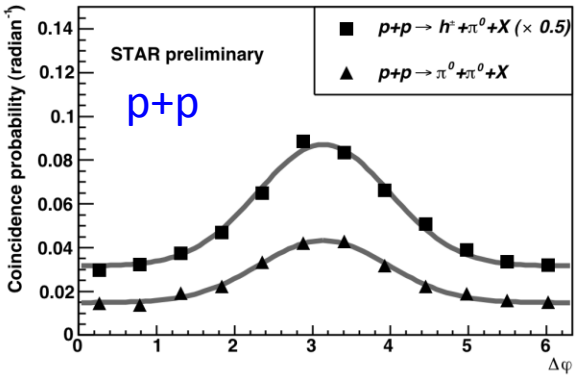
- Forward (FMS) π^0 trigger particle
- Mid-rapidity (BEMC/TPC) $\pi^0/h^{\pm}$ associated particle
- Includes efficiency and background corrections

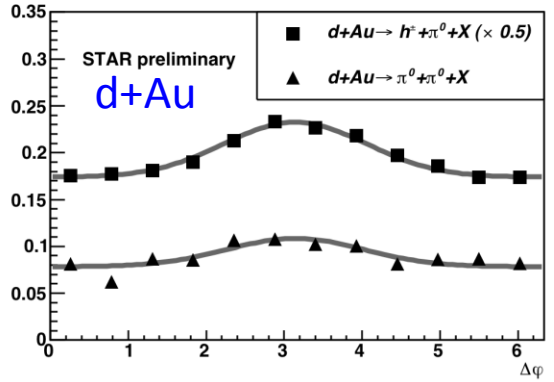
P_T(FMS) > 2.5 GeV/c ; 1.5 GeV/c < P_T(BEMC/TPC) < P_T(FMS)





P_T(FMS) > 2.0 GeV/c ; 1.0 GeV/c < P_T(BEMC/TPC) < P_T(FMS)



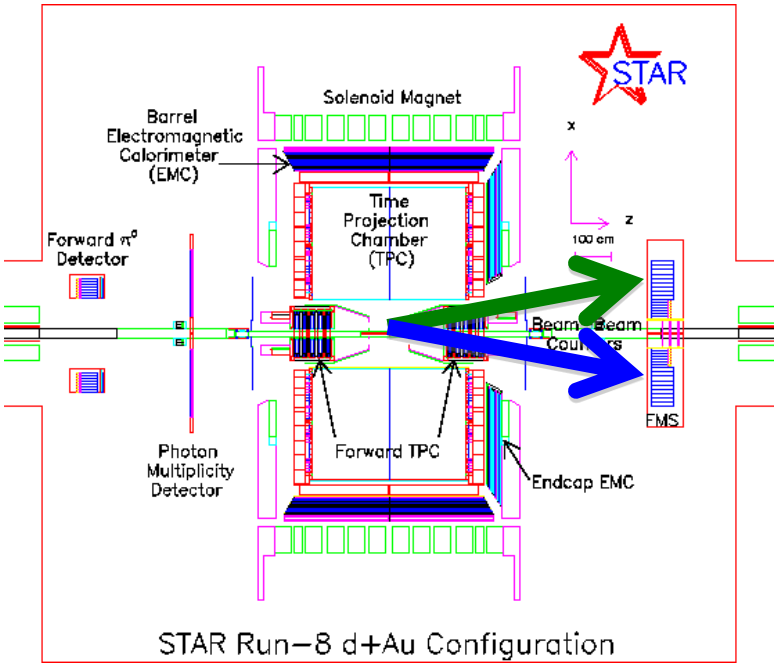


Ermes Braidot (arXiv:1102.0931)

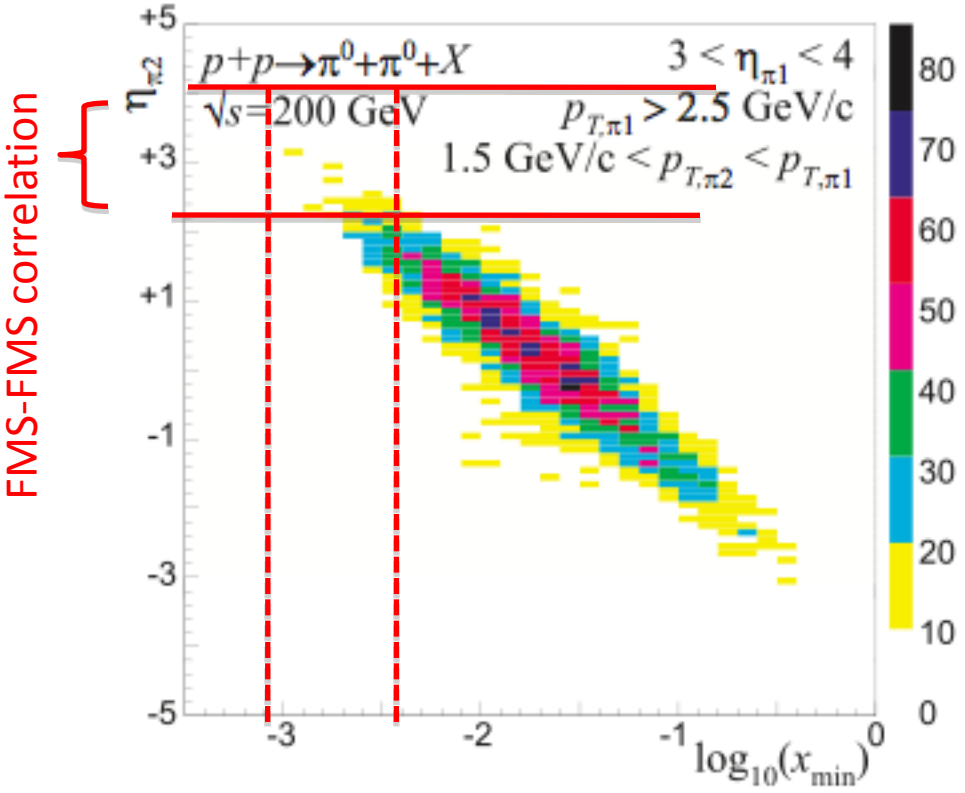
- No significant broadening from p+p to d+Au
- No hints of away-side peak disappearance

Forward-Forward Rapidity Correlations

- Probe gluon density at $0.0009 < x < 0.005$



PYTHIA simulation

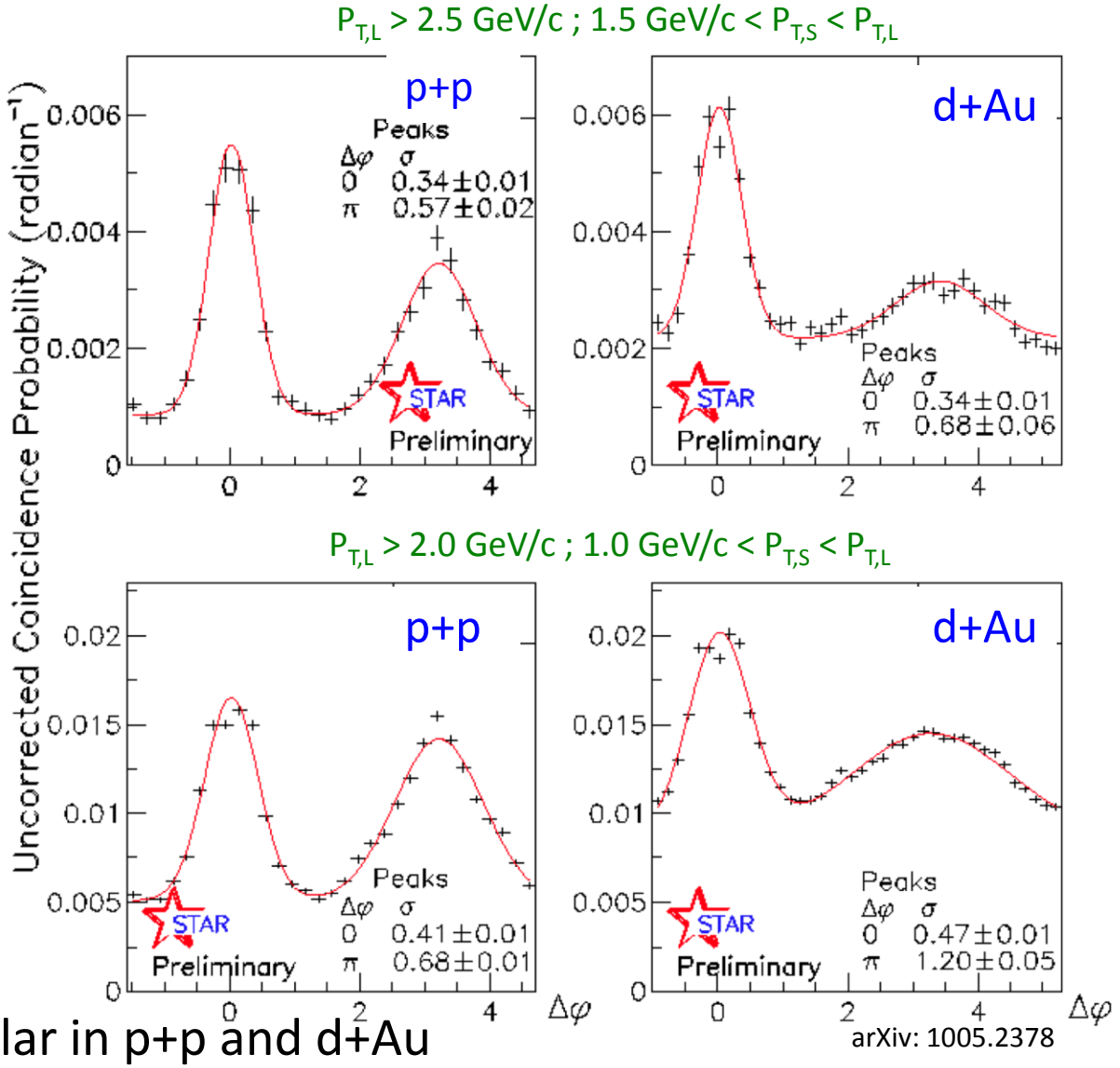


- Look at forward-forward correlations to access lowest x region

Forward-Forward Rapidity Correlations

- Forward (FMS) π^0 trigger particle
- Forward (FMS) π^0 associated particle
- Centrality Averaged

- Not yet efficiency or background corrected

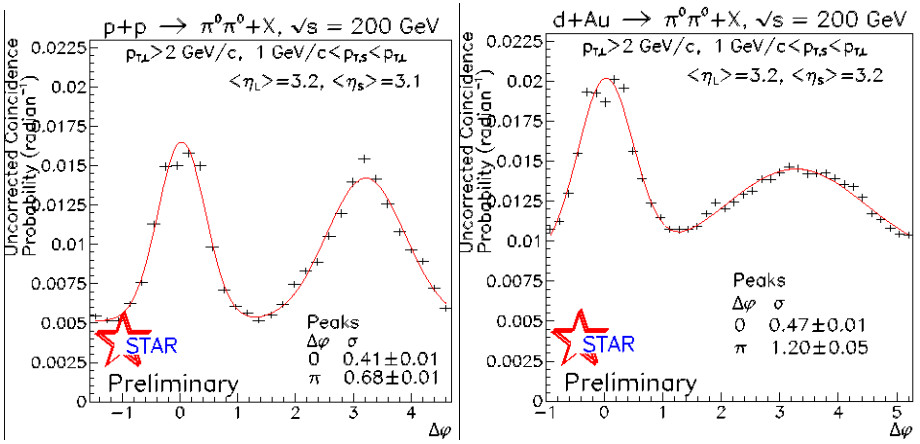


arXiv: 1005.2378

- Near-side peak is similar in p+p and d+Au
- Significant broadening from p+p to d+Au in the away side peak.

Forward-Forward Rapidity Correlations: Centrality Dependence

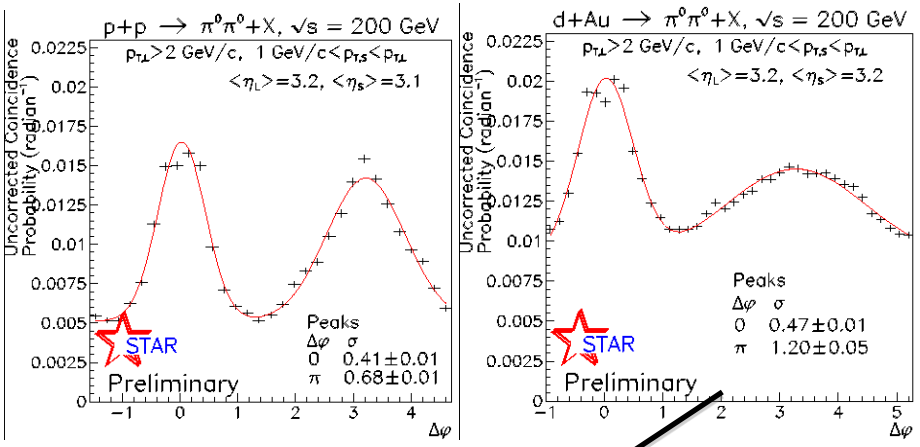
p+p Centrality Averaged d+Au



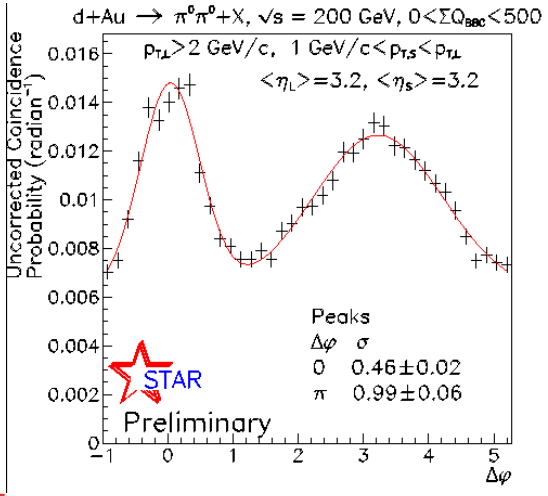
- Centrality selection from Au-side (East) BBC charge sum
- Near-side peak similar in p+p and d+Au

Forward-Forward Rapidity Correlations: Centrality Dependence

p+p Centrality Averaged d+Au



Peripheral



- Centrality selection from Au-side (East) BBC charge sum
- Near-side peak similar in p+p and d+Au
- Peripheral d+Au Away-side peak similar to p+p

Forward-Forward Rapidity Correlations: Centrality Dependence

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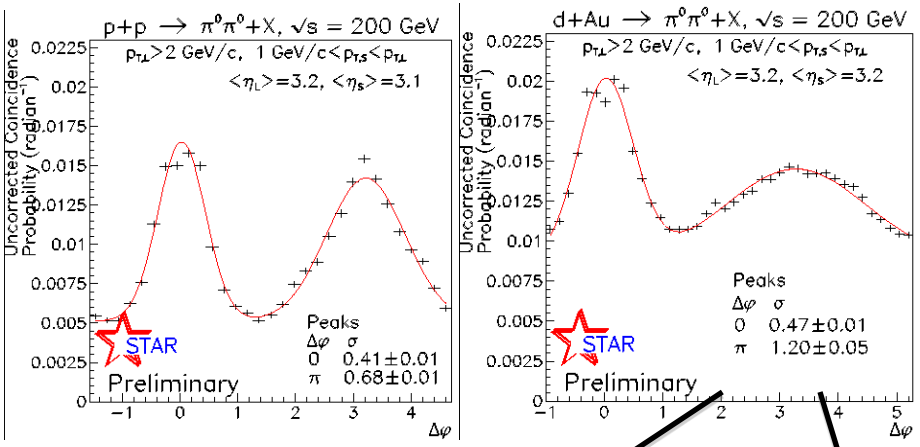
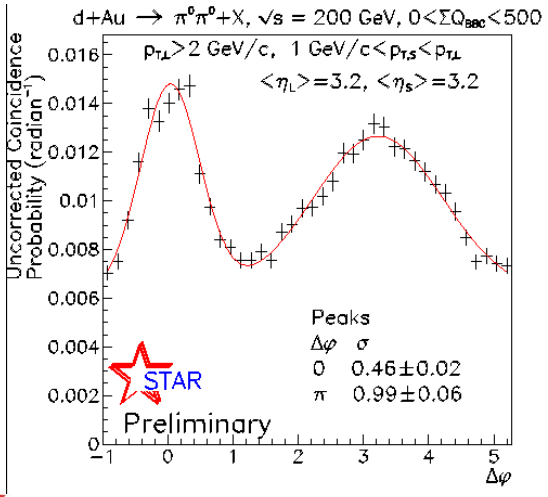
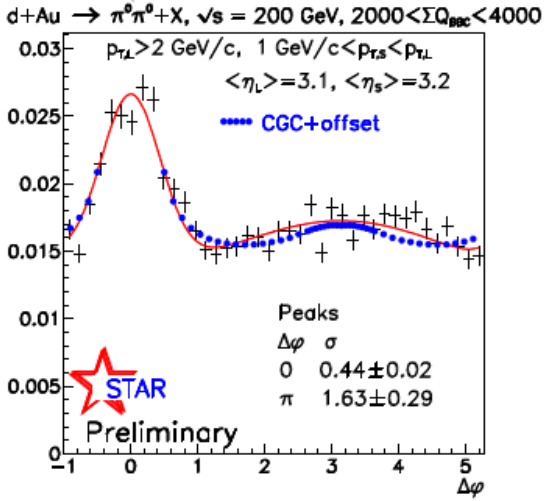


- Centrality selection from Au-side (East) BBC charge sum
- Near-side peak similar in p+p and d+Au
- Peripheral d+Au Away-side peak similar to p+p
- Central d+Au Away-side peak shows strong suppression and good agreement with CGC model calculation

Peripheral



Central

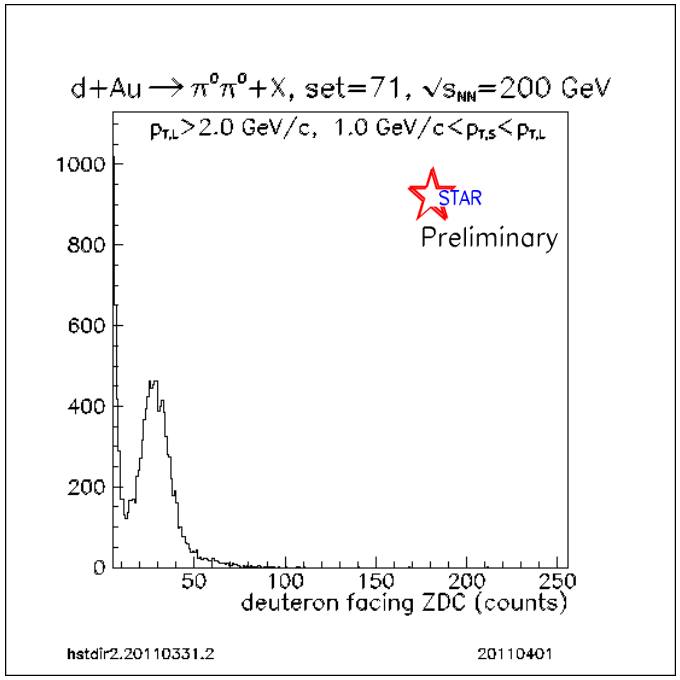


- Model : Albacete, Marquet (arXiv: 1005.4065)
- Model : b = 0
- Data : <b> = 2.7fm

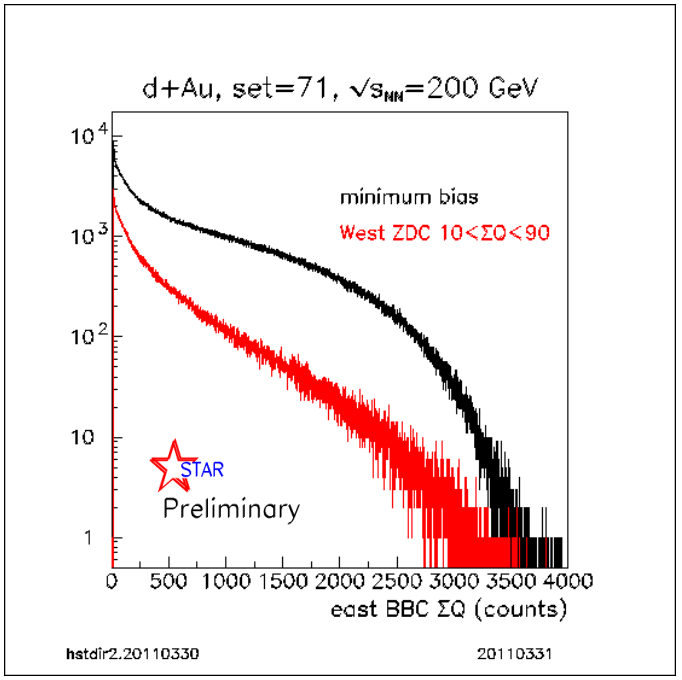
Tagging Spectator Neutrons from Deuteron Beam

- It may also be useful to distinguish between p+Au and d+Au collisions by looking for events where the neutron in the deuteron remains intact

Deuteron-facing (West) ZDC Response



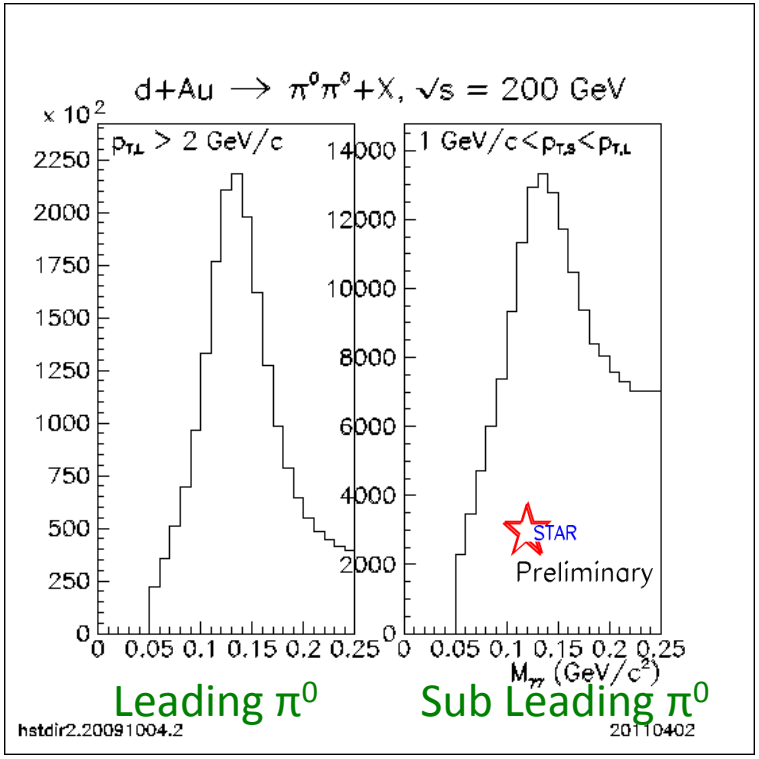
Gold-facing (East) BBC Charge Sum



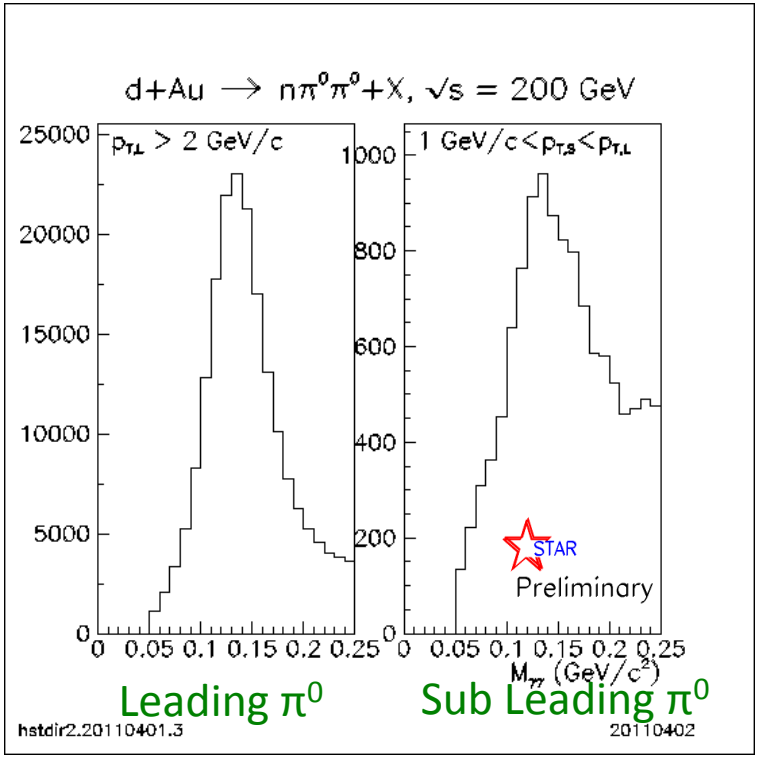
- Minimum Bias Run 8 d+Au Data
- Tag spectator neutrons using deuteron-facing (West) ZDC
- Clear single-neutron peak
- Cutting on single-neutron peak biases towards peripheral collisions

Di-Pion Invariant Masses

d+Au, Centrality Averaged, No Neutron Tag

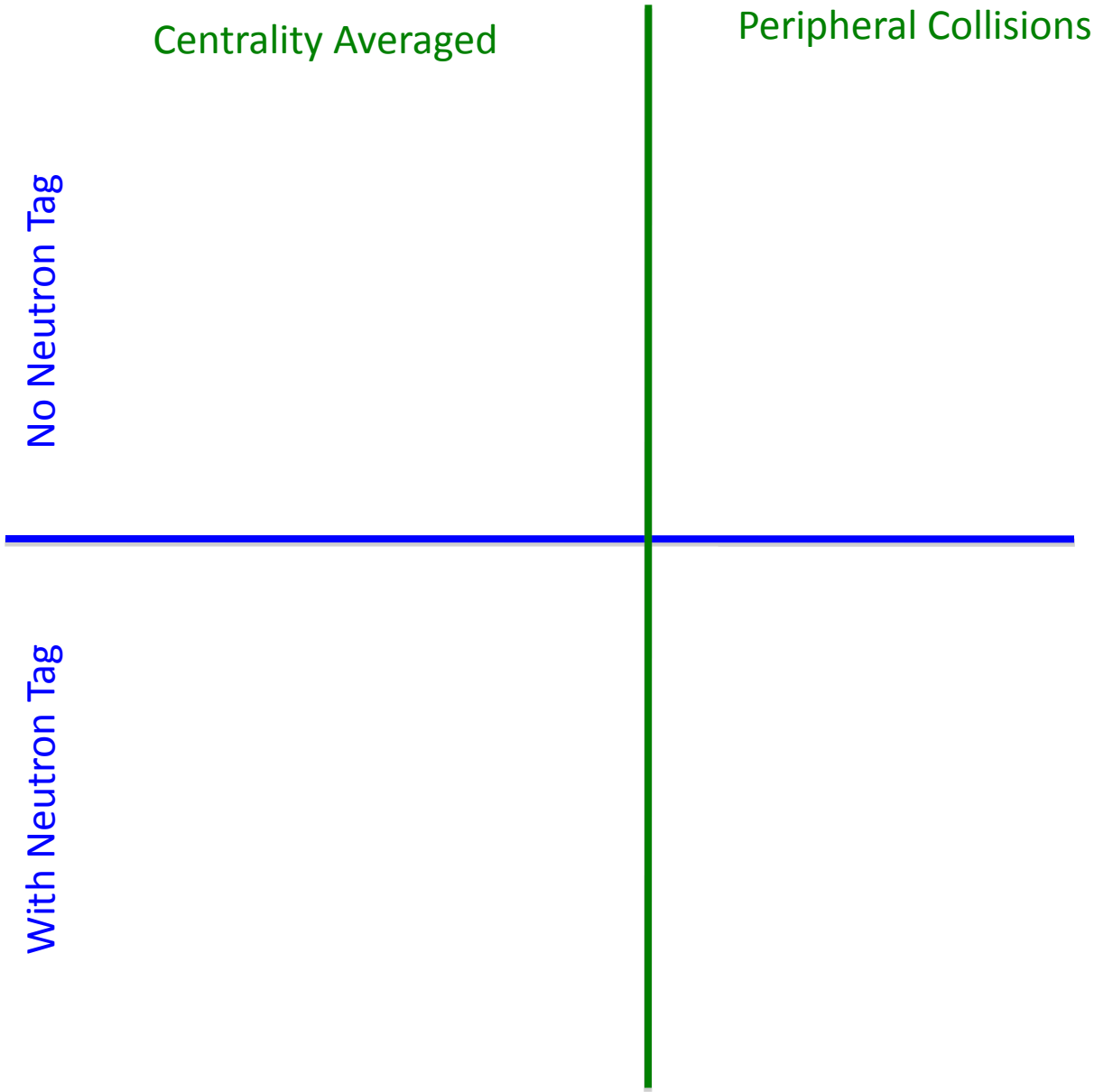


d+Au, Centrality Averaged, With Neutron Tag



- Similar Invariant Mass distributions with and without neutron tagging
- Efficiency Corrections of Azimuthal Correlations should be similar with and without neutron tagging

Forward Di-Pion Azimuthal Correlations with Neutron Tag



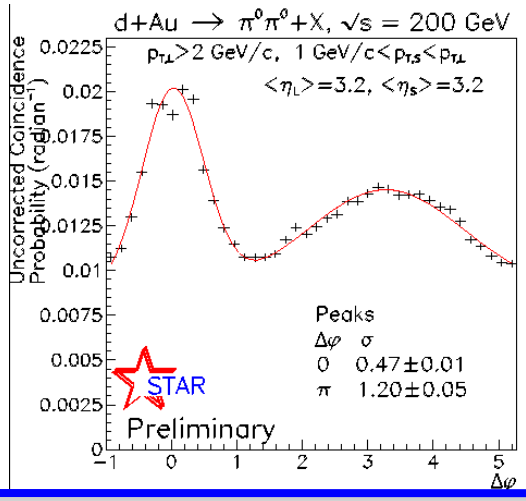
Forward Di-Pion Azimuthal Correlations with Neutron Tag

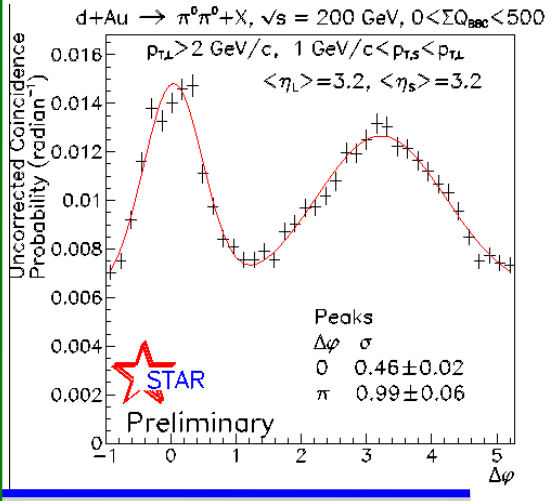
Centrality Averaged

Peripheral Collisions

No Neutron Tag

With Neutron Tag





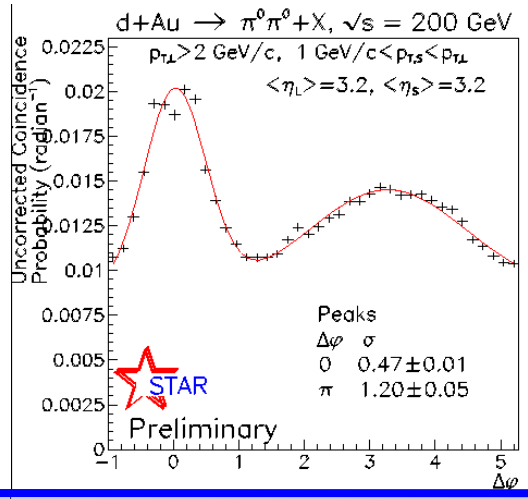
Forward Di-Pion Azimuthal Correlations with Neutron Tag

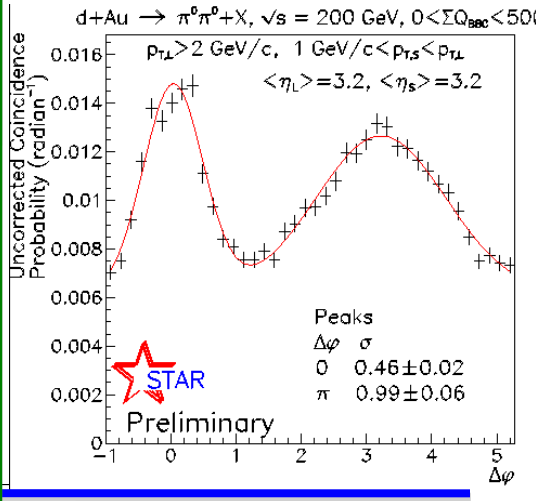
- Inclusion of west ZDC spectator neutron condition reduces the pedestal
- Pedestal from d+Au correlations with neutron tag are quantitatively consistent with pedestal in p+p correlations
- Little impact on peak heights above pedestal or widths with spectator neutron condition
- Study of systematics in progress

Centrality Averaged

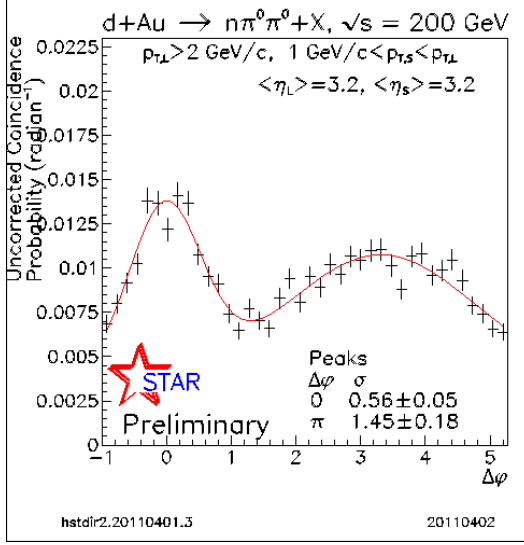
Peripheral Collisions

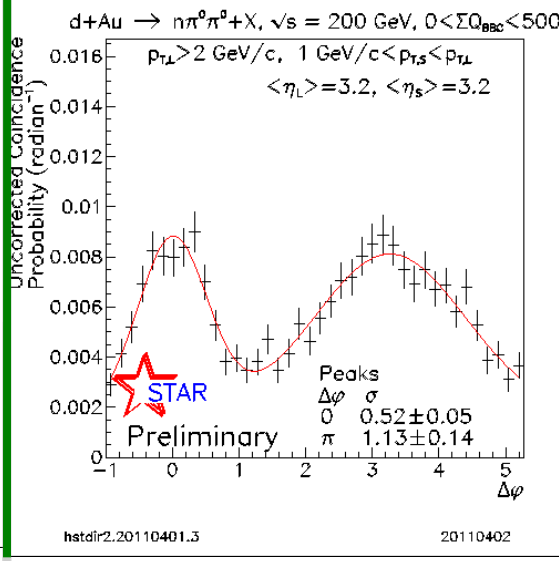
No Neutron Tag





With Neutron Tag





Forward Di-Pion Azimuthal Correlations with Neutron Tag

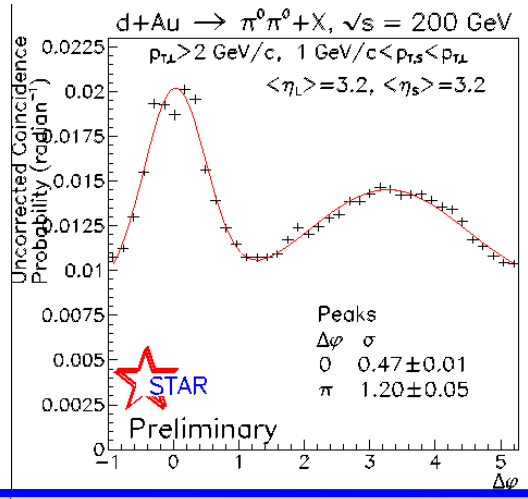
- Inclusion of west ZDC spectator neutron condition reduces the pedestal
- Pedestal from d+Au correlations with neutron tag are quantitatively consistent with pedestal in p+p correlations
- Little impact on peak heights above pedestal or widths with spectator neutron condition
- Study of systematics in progress
- Some theorists have argued that multi-parton interactions will affect the pedestal level

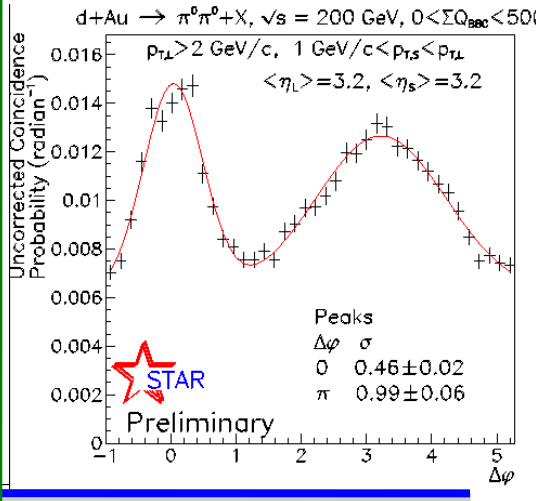
  (Strickman, Vogelsang arXiv: 1009.6123)
- Data indicates that multi-parton interactions appear to contribute to the pedestal in d+Au collisions more than p+Au collisions
- Other basic aspects of the azimuthal correlations appear to be unchanged between d+Au and p+Au collisions

Centrality Averaged

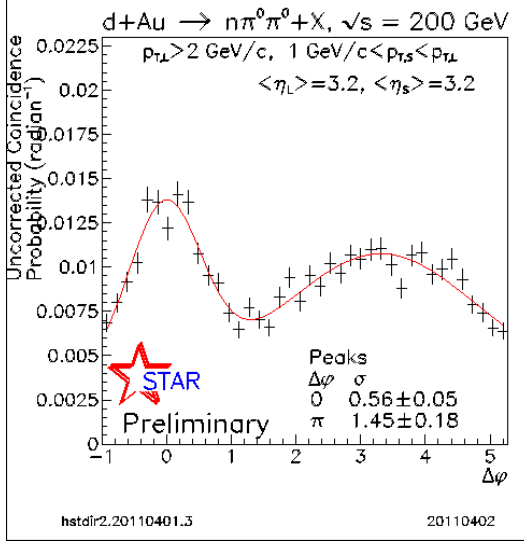
Peripheral Collisions

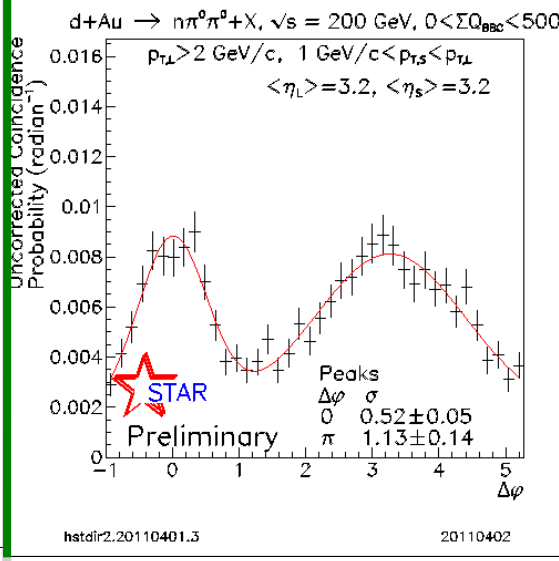
No Neutron Tag





With Neutron Tag



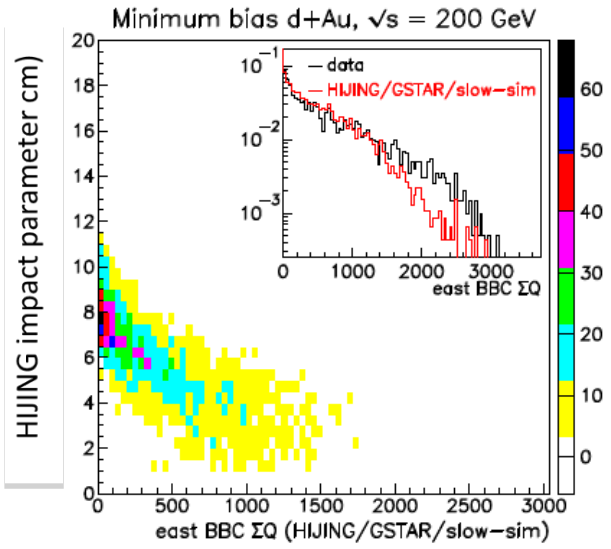


Conclusions and Outlook

- Forward-Mid Di-Hadron Azimuthal Correlations:
  - No significant Away-side peak broadening
- Forward-Forward Di-Pion Azimuthal Correlations:
  - Near-side peak is similar between p+p and d+Au
  - Significant broadening in Away-side peak between p+p and d+Au
  - Peripheral Away-side peak similar between p+p and d+Au
  - Central Away-side peak shows strong suppression
- Tagging spectator neutron from deuteron may differentiate between p+Au and d+Au
  - Multi-parton interactions may contribute to pedestal in d+Au but not p+Au collisions
  - Other basic aspects of azimuthal correlations appear unchanged between d+Au and p+Au
- Efficiency and background corrections for forward-forward azimuthal correlations in progress
- Analysis of intermediate pseudorapidity region between forward and mid-rapidity is currently in progress using EEMC

Backup

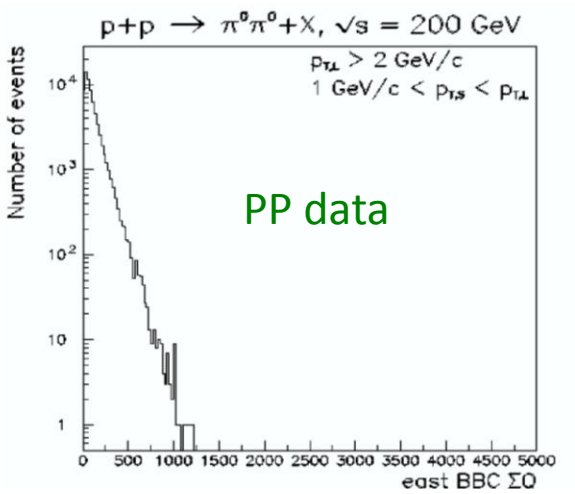
Centrality Determination in d+Au

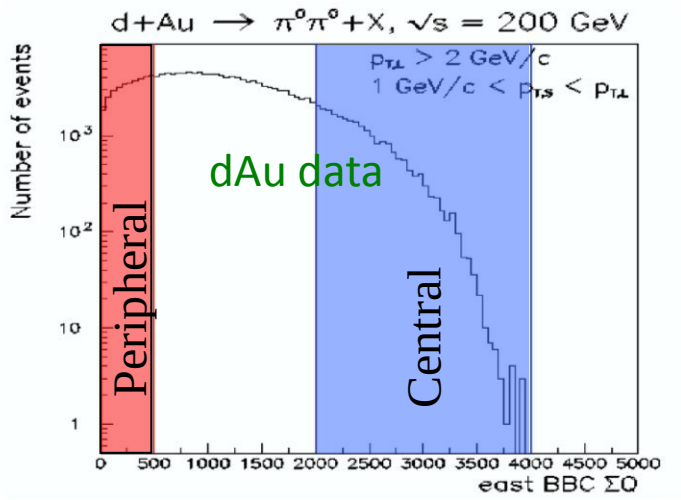


The impact parameter is related with the charge sum in the east BBC by a model.

East BBC charge sum	Average impact parameter (fm)
0 - 500	6.8 ± 1.7
2000 - 4000	2.7 ± 1.3

arXiv:hep-ex/1005.2378





- Multiplicity in d+Au measured by the east beam beam counter (BBC) at STAR reflects the centrality.